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Influence of Jacking Oil Grooves in Two-Lobe Bearings on Bearing Performance

Dr. Henning Ressing, Philipp Köster,
Dr. Kai Ziegler, MAN Diesel & Turbo SE

Dr. Martin Conlon, Dr. Azzedine Dadouche
National Research Council Canada
David Evans, Dan Turton
Waukesha Bearings Ltd.

42nd Turbomachinery
29th Pump SYMPOSIA

GEORGE R. BROWN CONVENTION CENTER
9.30 – 10.3.2013

MAN

TEXAS A&M ENGINEERING TEES TURBOMACHINERY LABORATORY

ATM

Authors

- **Dr. Henning Ressing** studied Mechanical Engineering at the University of Siegen, Germany and received his Ph.D. from The University of British Columbia, Canada focusing on crack identification in rotating machinery. He then spend time at AUDI in Ingolstadt, Germany working as an engine development engineer. In 2006 he joined MAN Diesel & Turbo in Oberhausen, Germany as a specialist for compressor rotordynamics and structural mechanics and is now heading the department for Calculation and R&D Compressors.
- **Philipp Köster** studied mechanical Engineering at the University of Siegen, Germany. After receiving his diploma in 2006 he focused his research on the simulation of short crack propagation. He joined MAN Diesel & Turbo in Oberhausen, Germany as a development engineer in the department for Calculation and R&D Compressors in 2011. Since then he has worked on R&D projects in the field of structural mechanics and rotordynamics of turbo compressors.
- **Dr. Kai U. Ziegler** received his Dr.-Ing. degree from RWTH Aachen, Germany focusing on turbomachinery aerodynamics. He then joined MTU in Munich as a development engineer for aero engines before moving on to MAN Diesel & Turbo in Oberhausen, Germany in 2005, where he became the Head of Calculation / R&D Compressors. As Vice President Engineering Compressors he now oversees all engineering activities for compressor technology in MAN Diesel & Turbos's Business Unit Process Industry.
- **Dr. Martin J. Conlon** studied Mechanical and Aerospace Engineering at Carleton University, focusing on the nonlinear dynamics of mechanical/fluid systems. He joined the National Research Council Canada in 2007 and has since focused his research on the experimental evaluation of aerodynamic and hydrodynamic bearing performance.
- **Dr. Azzedine Dadouche** is an associate research officer at the National Research Council Canada (NRC). He obtained his Master and Ph.D. in mechanical engineering from the University of Poitiers in 1995 and 1998 respectively. Before joining NRC in 2004, he taught at the University of Science and Technology of Oran (Algeria) and worked as a design engineer in Quebec. His research focus is on rotating components health management and rotor support systems performance evaluation.
- **David Evans** is a Principal Engineer at Waukesha Bearings Ltd, located in Middlesex, United Kingdom. Mr. Evans serves some of Waukesha's European customers and is responsible for the design and specification of hydrodynamic bearings for turbomachinery and also oversees the development of the company's in-house engineering software. He joined the Glacier Metal Company in 1977 to work on the application of fixed profile bearings to rotating plant, transferring to Waukesha Bearings in 2001. Mr. Evans graduated from Clare College, Cambridge in 1973 and worked at GEC Mechanical Handling from 1973 to 1977.
- **Dan Turton** is a Senior Project Engineer at Waukesha Bearings Ltd, located in Middlesex, United Kingdom. Mr. Turton serves some of Waukesha's European customers and is responsible for the design and specification of hydrodynamic bearings for turbomachinery including those for land based power generation, subsea and research and development applications. Mr. Turton joined Waukesha Bearings in 2007. Mr. Turton received his Bachelor's of Engineering in 1992 from the University of Hull and is a member of the Institute of Mechanical Engineers.

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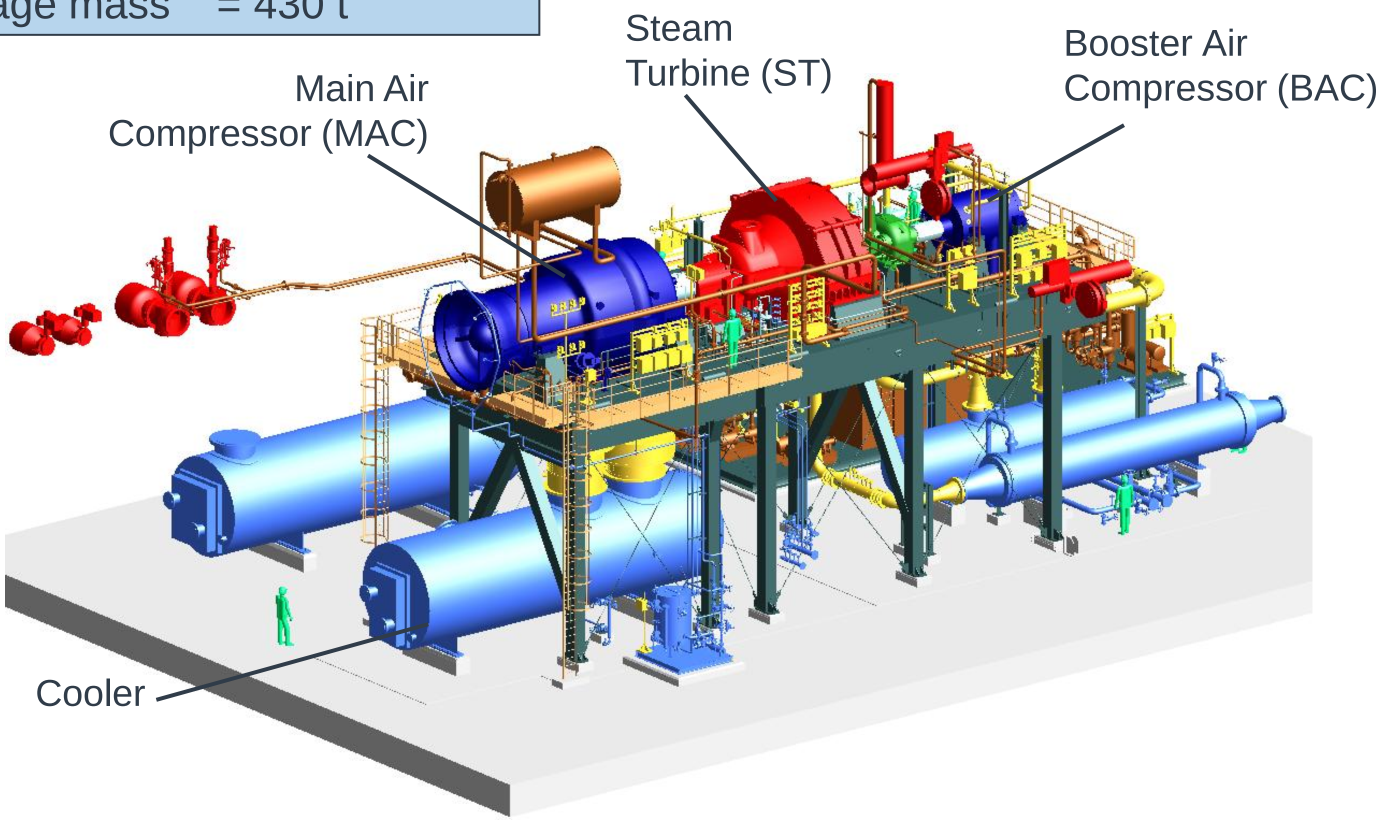
Introduction

Layout of MAN Diesel & Turbo ASU-train

Train capacity	= 3500 tpd O2
Train power	= 74 MW
Machine package mass	= 430 t



World wide 12 references, some of which have been running for more than 5 years.

Introduction

Design of Axial/Radial Main Air Compressor

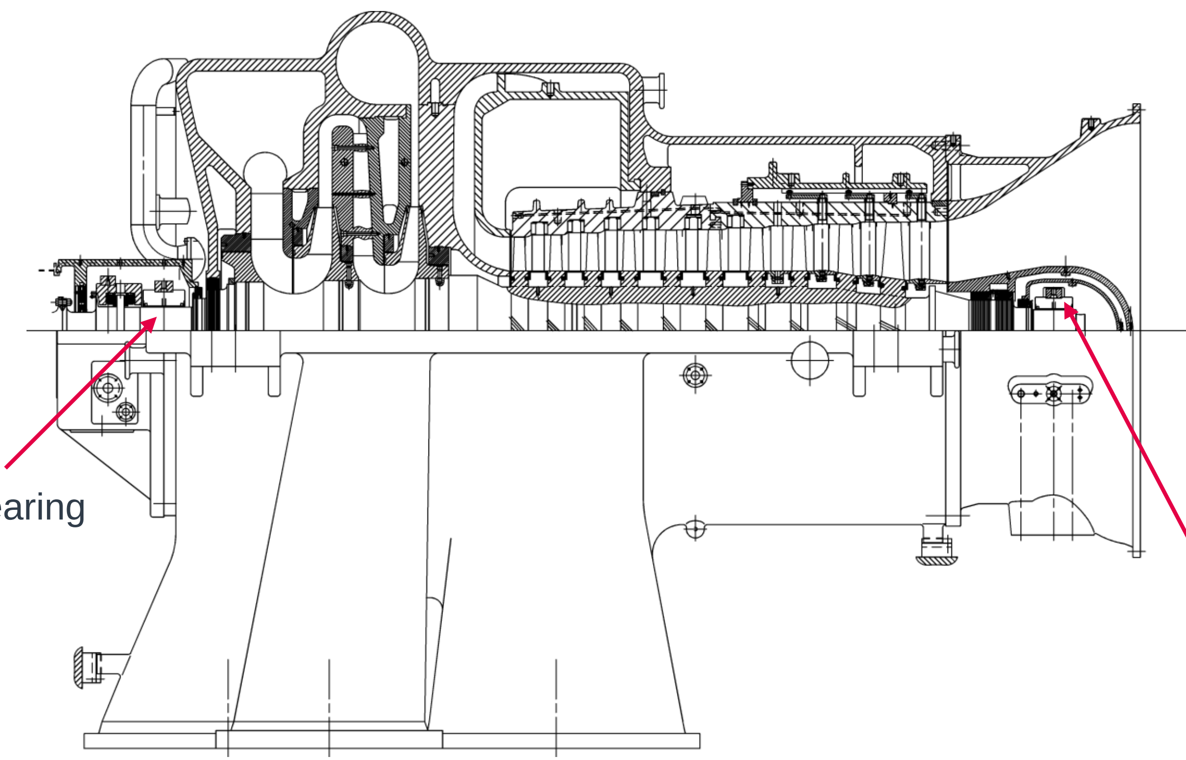
2 radial stages

10 axial stages

V_{eff} = 650 000 m³/h

p_{in} = 1 bara

p_{out} = 8.5 bara



axial inlet

journal bearing drive end

journal bearing non-driven end

inlet after intercooler

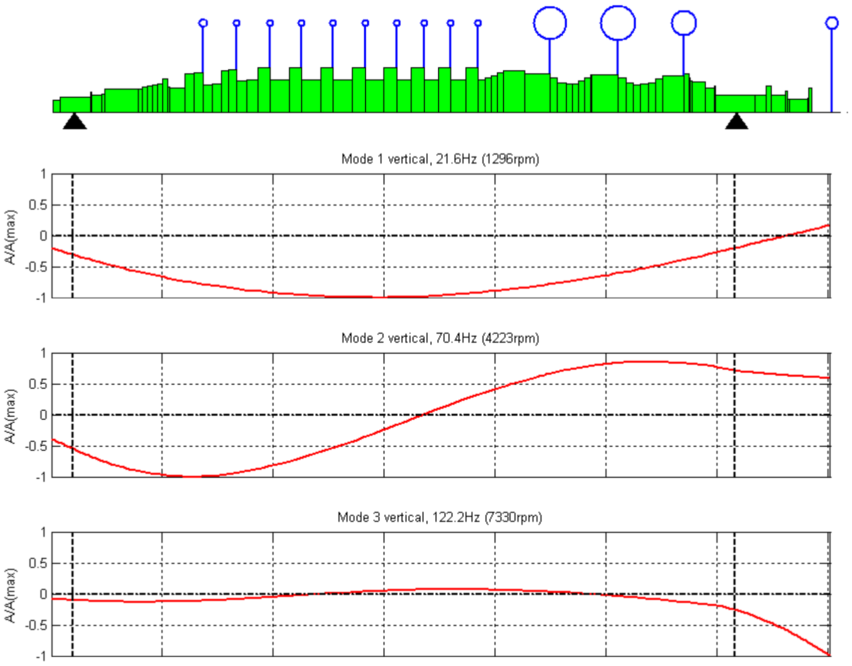
radial outlet

axial outlet to intercooler

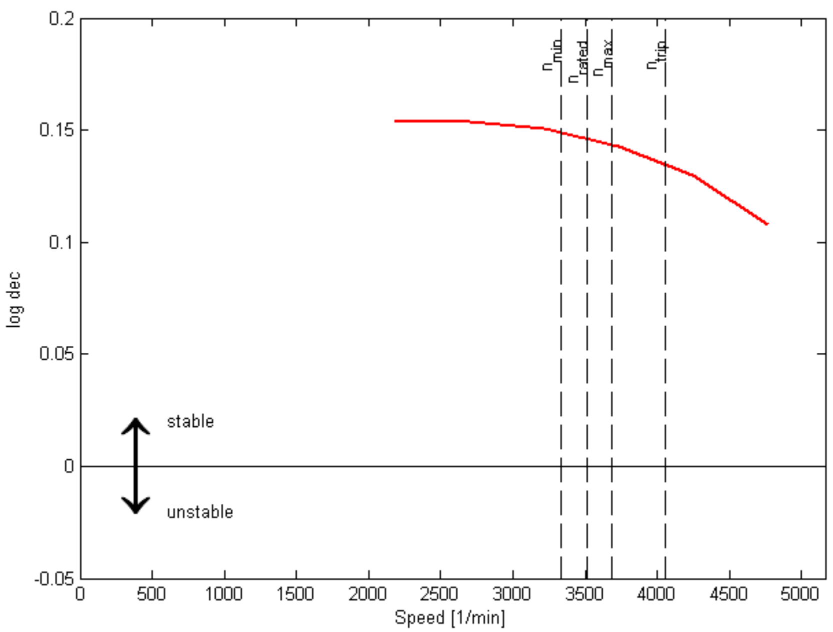
Axial Compressor Rotordynamics

Stability Analysis

- Main Air Compressor running with Waukesha two lobe bearings with jacking oil grooves
- 1st critical speed at 17 Hz (horizontal) and 22 Hz (vertical); N_{rated} at 3511rpm
- Min. log dec of mode 1 at N_{mcs}: 0.19 (horizontal) and 0.14 (vertical)



rotor model and vertical mode shapes 1-3



damping of mode 1 vertical

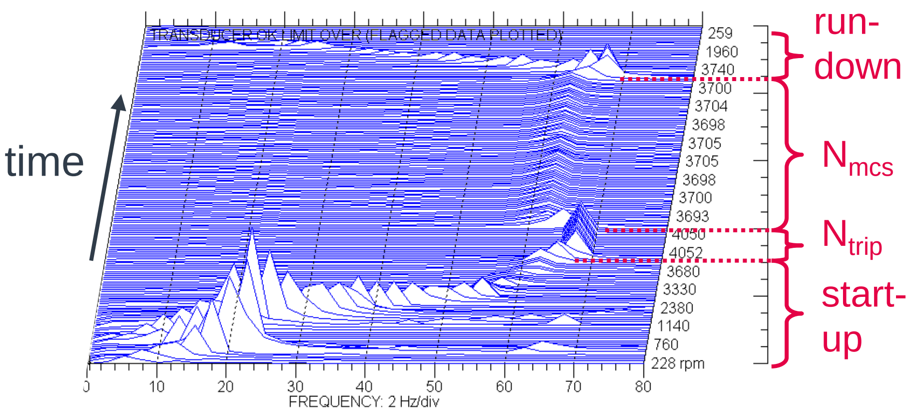
Rotor shows stable behavior over entire speed range

Subsynchronous Vibrations

Mechanical Running Test and Commissioning

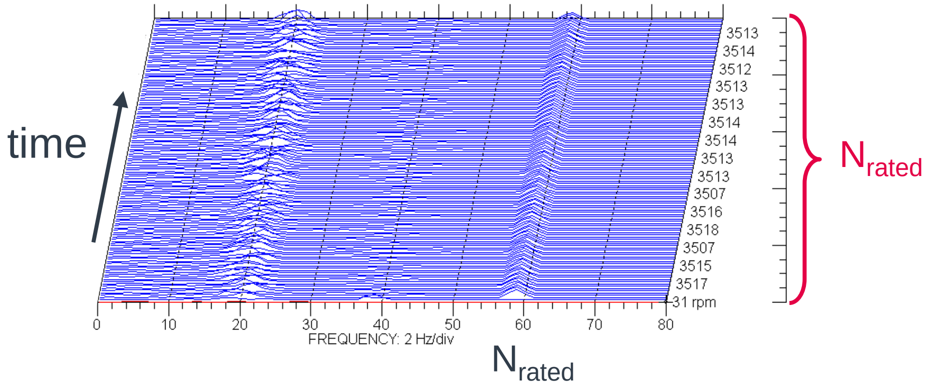
Mechanical Running Test

- A mechanical running test according to API617 was performed running the compressor up to trip speed.
- Measurement records show no sign of subsynchronous vibrations at N_{mcs}, N_{trip} or during start-up or run-down.



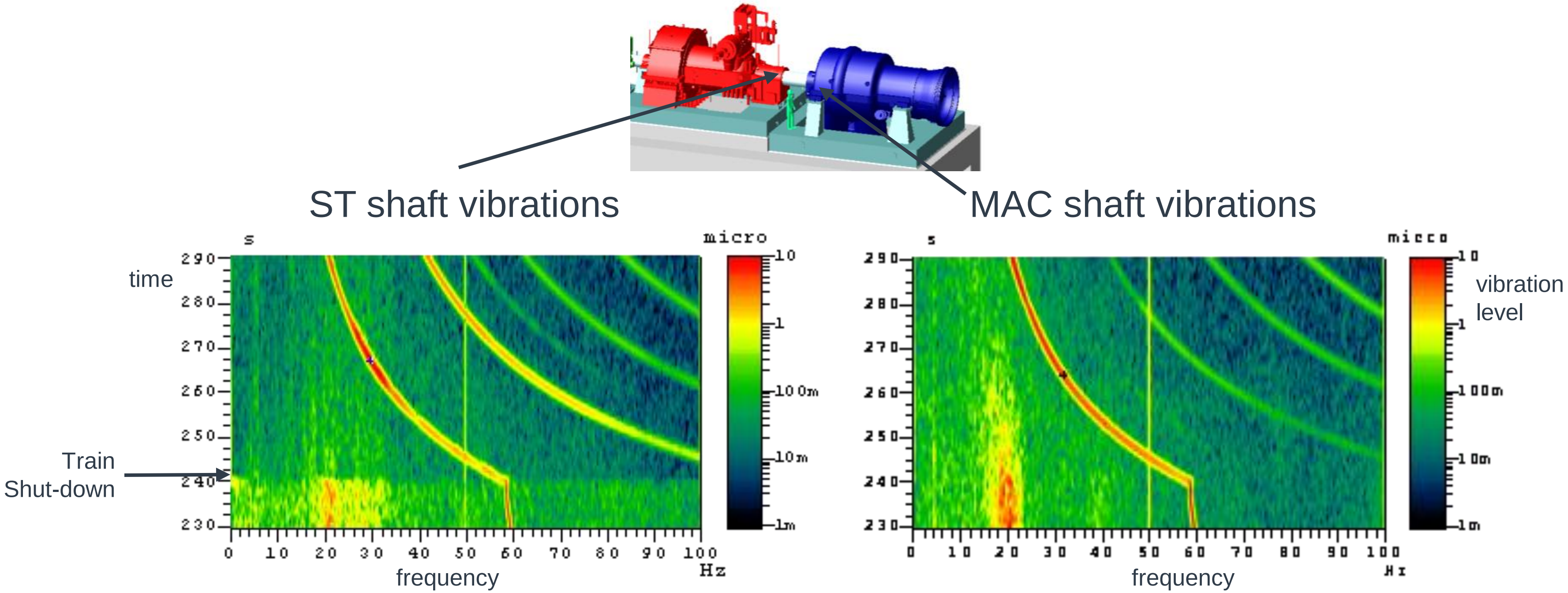
Commissioning

- During commissioning fluctuating subsynchronous vibrations (SSV) were measured at N_{rated}.



While MRT showed no SSV and proves good rotordynamic stability, on-site arrangement seems to introduce SSV component.

Root Cause Analysis

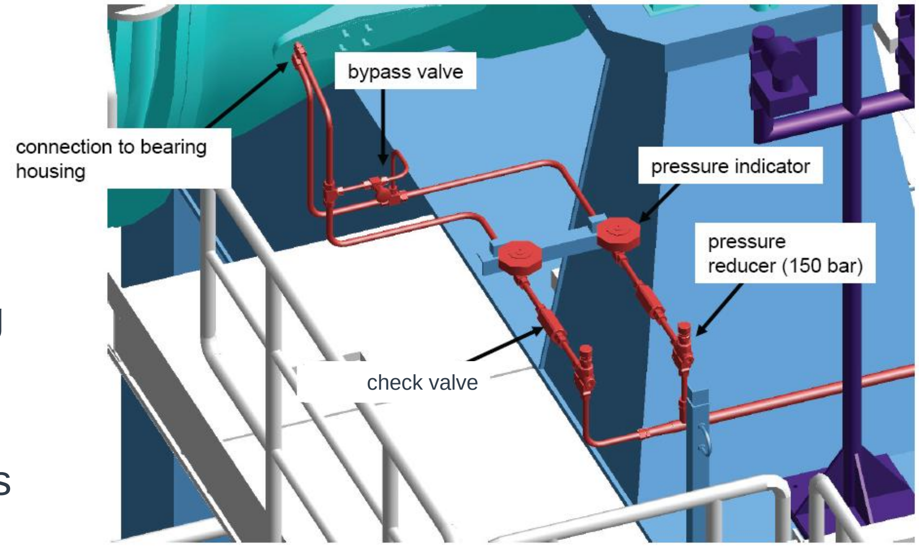


- A broad-band low frequency vibration component was found at various locations of the ASU-Train arrangement. It disappeared as soon as the train was shut-down.
- An extensive root cause analysis was conducted, the most likely cause was identified to be steam flow pulsations which coincided with strong vibrations of the live-steam piping system. No simple solution was found to avoid these vibrations.
- Reverberations of the MAC indicate that low frequency broad-band excitation is amplified in the 1st natural frequency. Therefore, an increase in damping of MAC should reduce SSV levels (fight the symptom, not the cause).

Journal Bearing Design

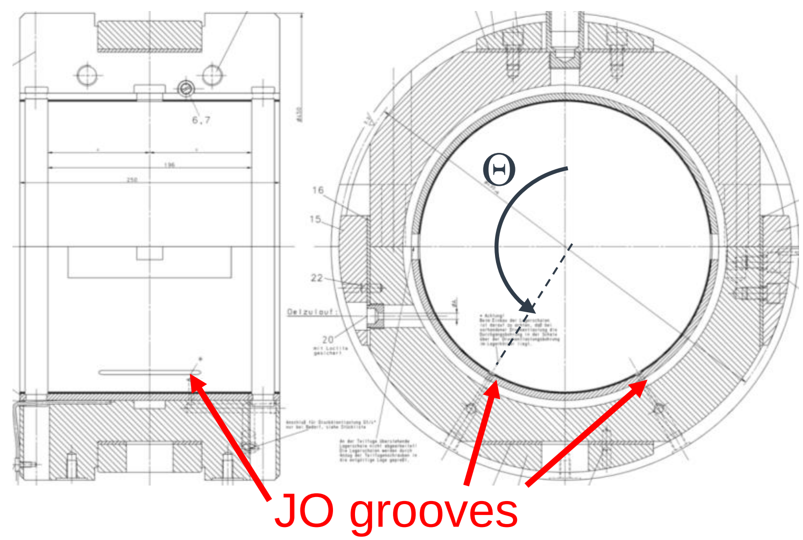
Layout of Jacking Oil System

- MAC equipped with jacking oil (JO) system for start up
- Backflow prevented by check valve during normal operation
- Due to previous experience JO lines are connected by bypass outside of the bearing housing
- Bypass valve can be opened allowing an equalization of the pressure in both JO lines



- Two lobe bearings with two jacking oil grooves in axial direction (at 150° and 210°)

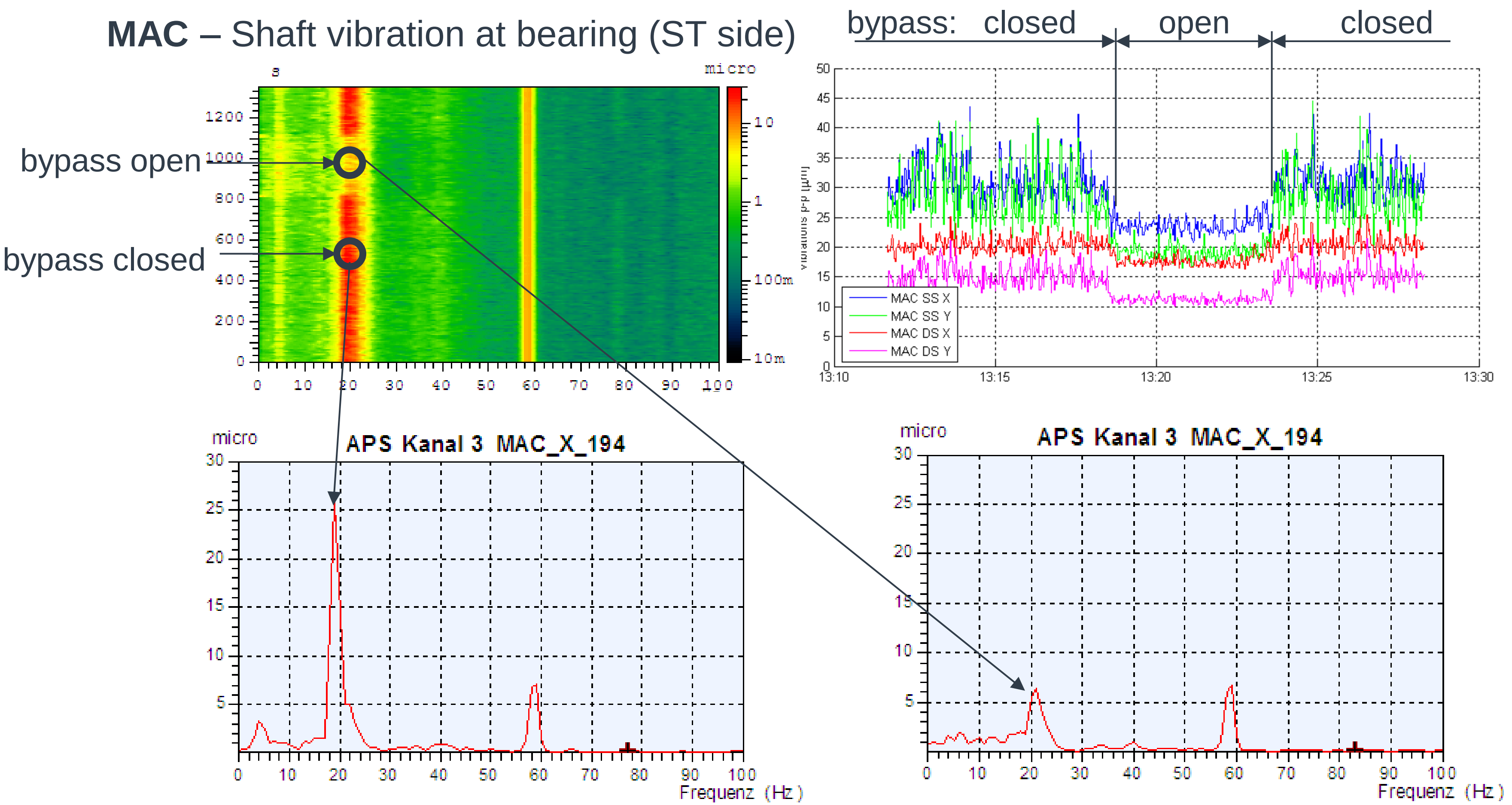
	suction side	pressure side
Diameter [mm]	280	315
L / D	0.7	0.7
Preload	0.52	0.52
Rel. clearance	1.38×10^{-3}	1.38×10^{-3}



Effect of Jacking Oil Bypass

Opening and Closing of Jacking Oil Bypass Valve

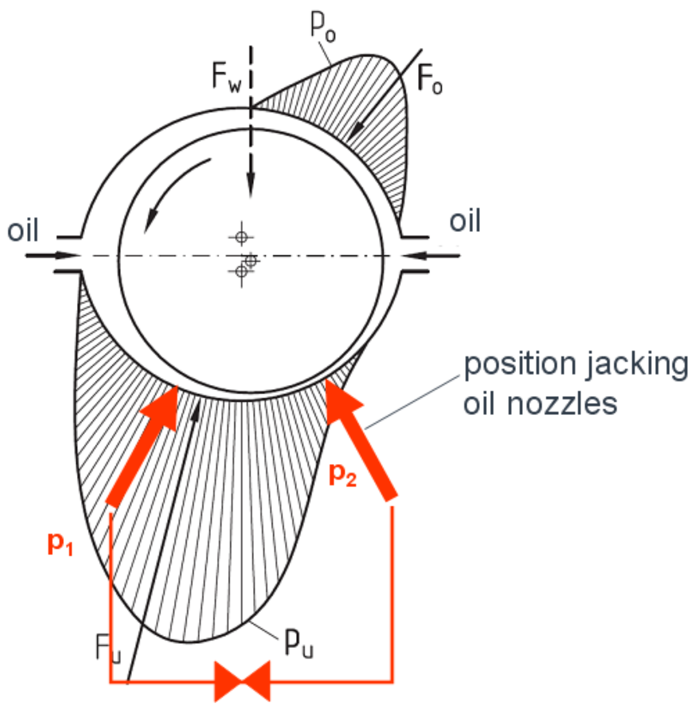
MAC – Shaft vibration at bearing (ST side)



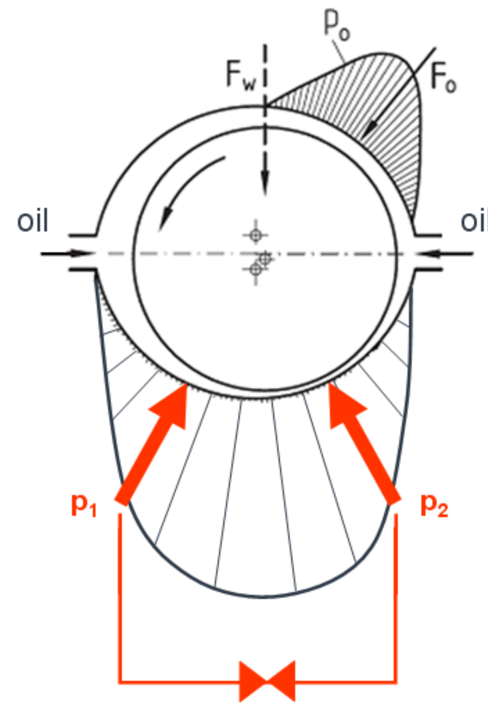
Opening the JO bypass valve reduces the SSV component by up to 70% of original level. Upon closing, SSV increase again to original level.

Effect of Jacking Oil Bypass

Influence of Jacking Oil System on Bearing Behavior



valve closed $p_1 \neq p_2$



valve open $p_1 = p_2$

Bypass valve closed

- Pressure difference between JO lines
- Maybe oscillation of oil column in JO line

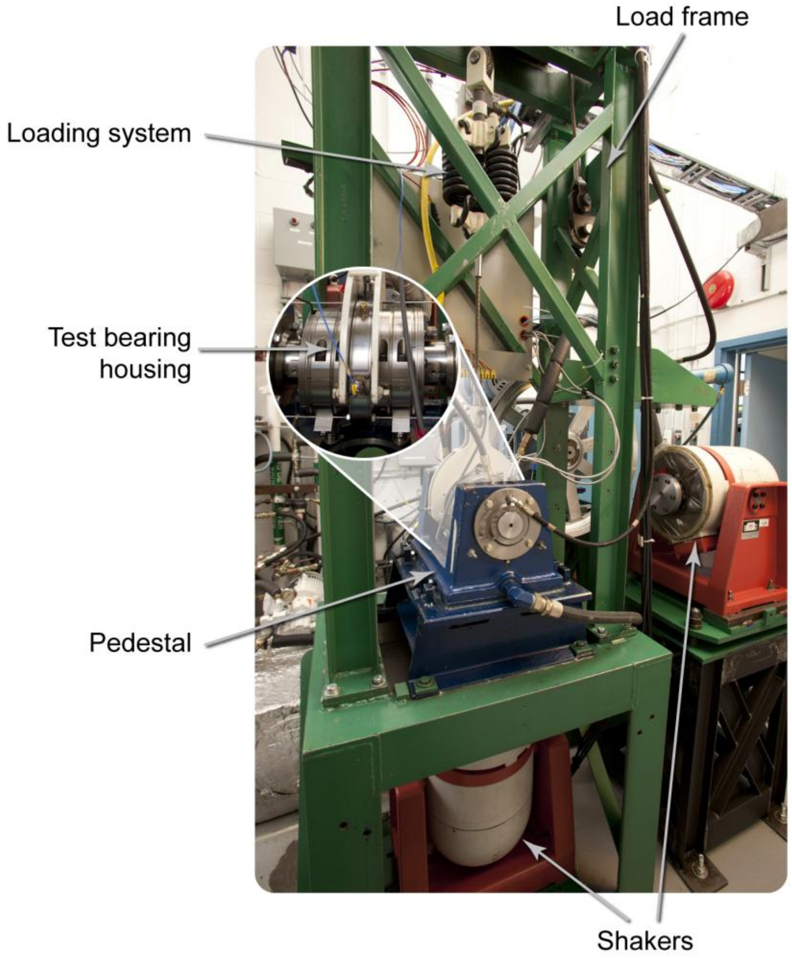
Bypass valve open

- Equalization of pressure in both JO lines
- Change in babbit pressure distribution yielding different shaft eccentricity
- Oil flow through bypass increases damping coefficients of bearing

Bearing Test

Bearing Test-Rig at NRC, Ottawa, Canada

- To further investigate the phenomenon a bearing test was carried out at the National Research Council, Ottawa, Canada (NRC).
- The aim was to measure the influence of the JO grooves and bypass on the static and dynamic bearing parameters.
- Two scaled test bearings were manufactured by Waukesha to fit into the NRC test rig:
  - one bearing with JO grooves,
  - one without JO grooves.

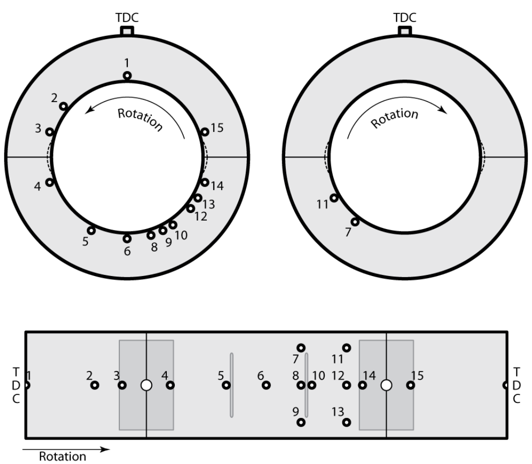


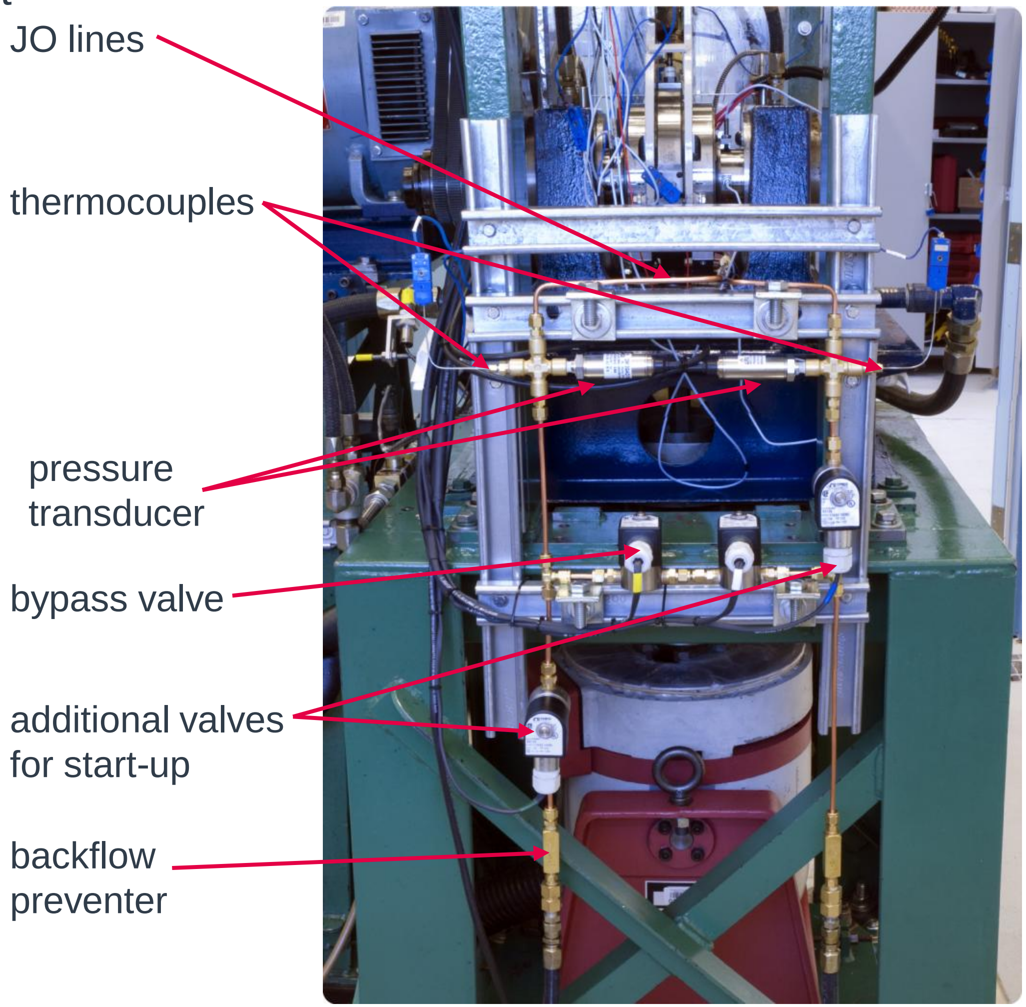
Test rig at the NRC

Bearing Test

Design of Jacking Oil System for Bearing Test

- The JO system of the test rig was built to simulate conditions of the MAC
- Thermocouples and pressure transducers were installed in both JO lines to measure oil temperature and oil pressure
- A special procedure was used for start-up to ensure that no air is trapped in the JO lines
- The babbit temperature was measured at 15 locations





Bearing Test

Design of Test Bearings

- Test bearing geometry scaled down from real MAC bearing

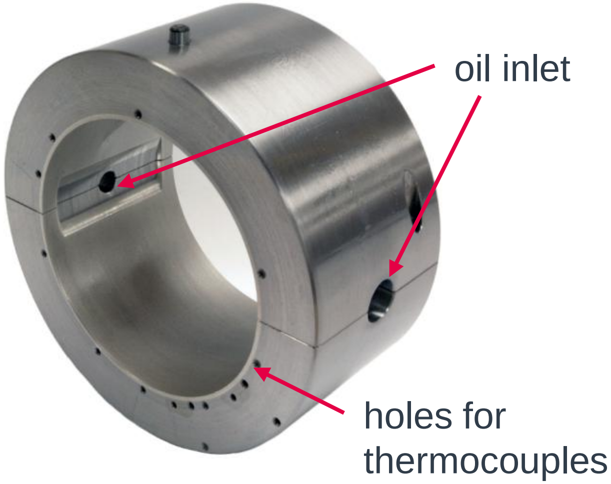
	MAC	Test bearing
Diameter [mm]	315	98.56
Length / Diameter	0.7	0.7
Preload	0.52	0.52
Rel. clearance	1.38×10^{-3}	1.38×10^{-3}

- Test matrix represents operating conditions of MAC

	speed [rpm]				
Spec. load	5590	7780	10130	11300	12380
1.0 MPa	x	x	x	x	x
1.5 MPa	x	x	x	x	x
2.0 MPa	x	x	x	x	x
2.5 MPa	x	x	x	x	x
3.0 MPa	x	x	x	x	x

spec. load and circumferential speed of MAC

Bearing 1 without JO grooves

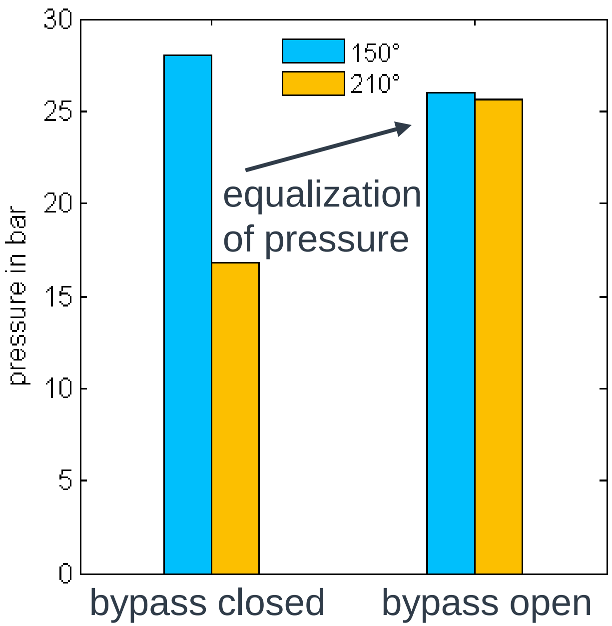


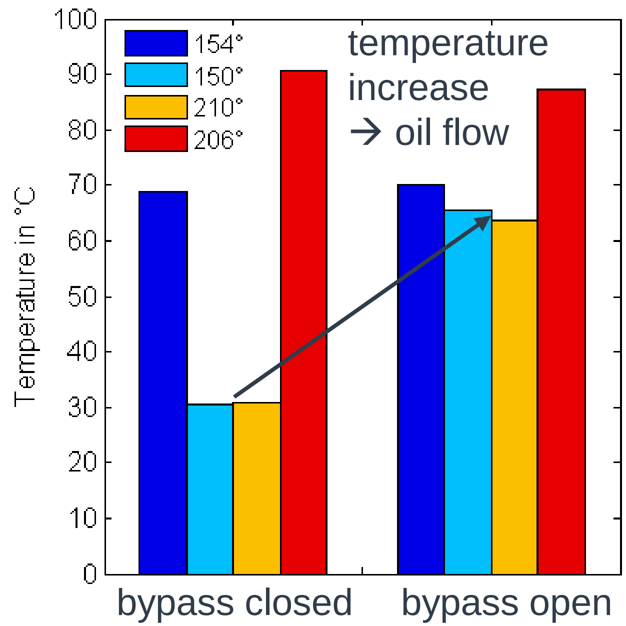
Bearing 2 with JO grooves

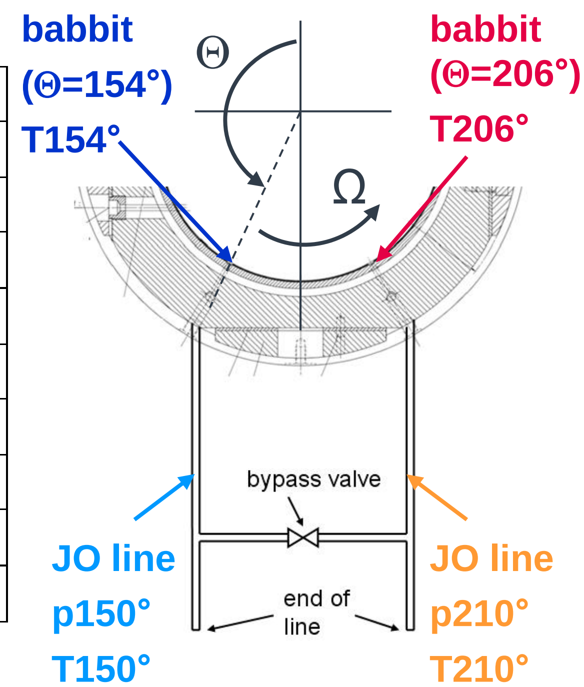
Bearing Test Results

Oil Pressure and Temperature in JO Line

Test result: p = 1,5MPa, N = 11300rpm
(specific load and circumferential speed of MAC)





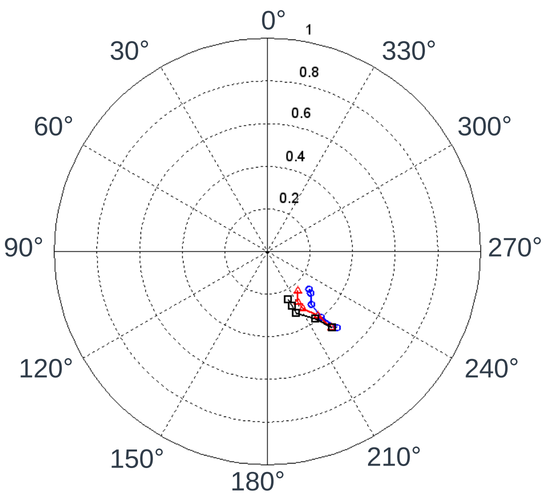


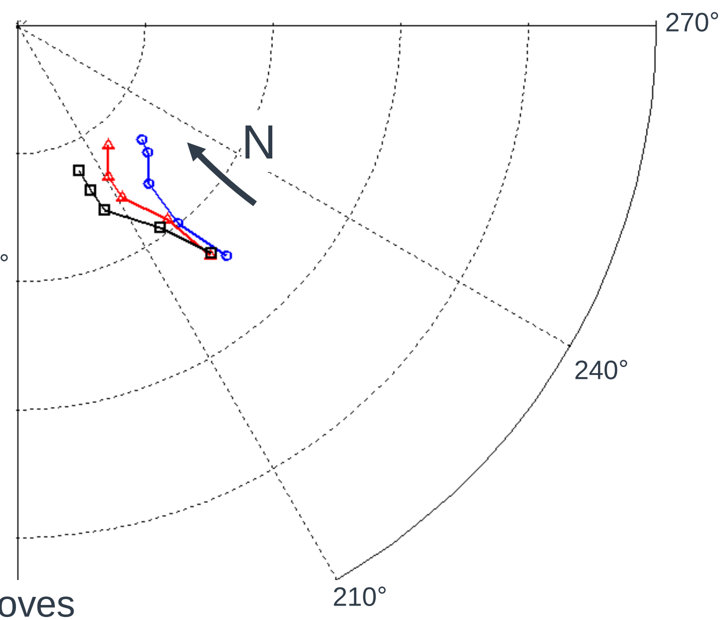
- JO system and bypass behaved as expected
- Opening of bypass yields equalization of pressure and oil flow in JO line
- For some load and running speeds the pressure p210° > p150° resulting in reversed oil flow direction

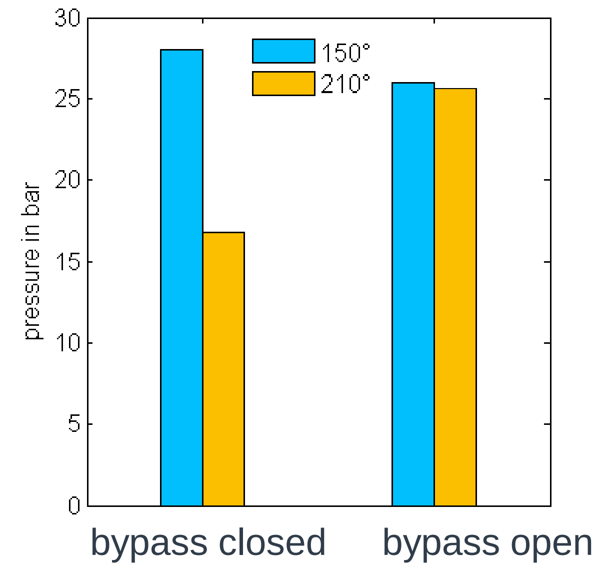
Bearing Test Results

Jacking Oil Bypass Influence on Shaft Eccentricity

Bearing eccentricity for p = 1,5MPa, all running speeds





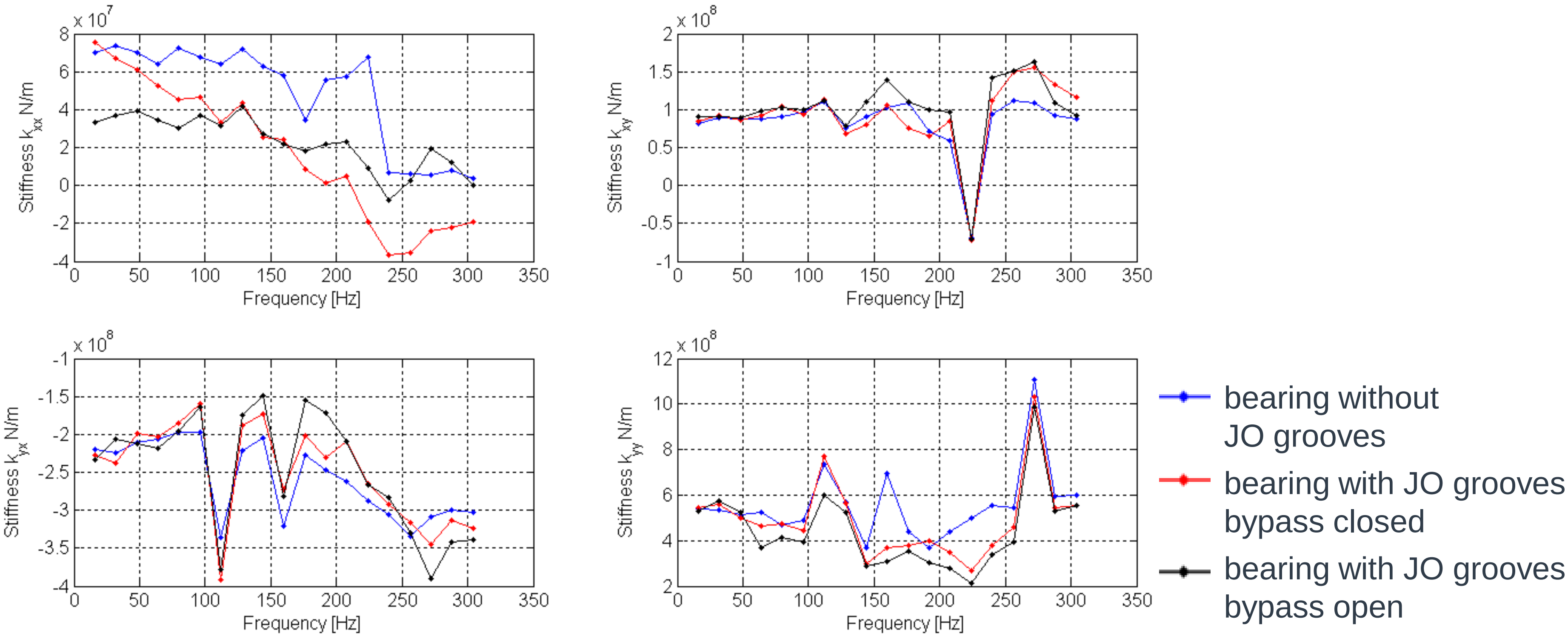


- bearing without JO grooves
- bearing with JO grooves, bypass closed
- bearing with JO grooves, bypass open

- Opening of bypass yields movement of shaft center to the inside
- Deflection caused by increased oil pressure at 210° position

Bearing Test Results

Stiffness Coefficients: 1,5MPa, 11300RPM (188Hz)

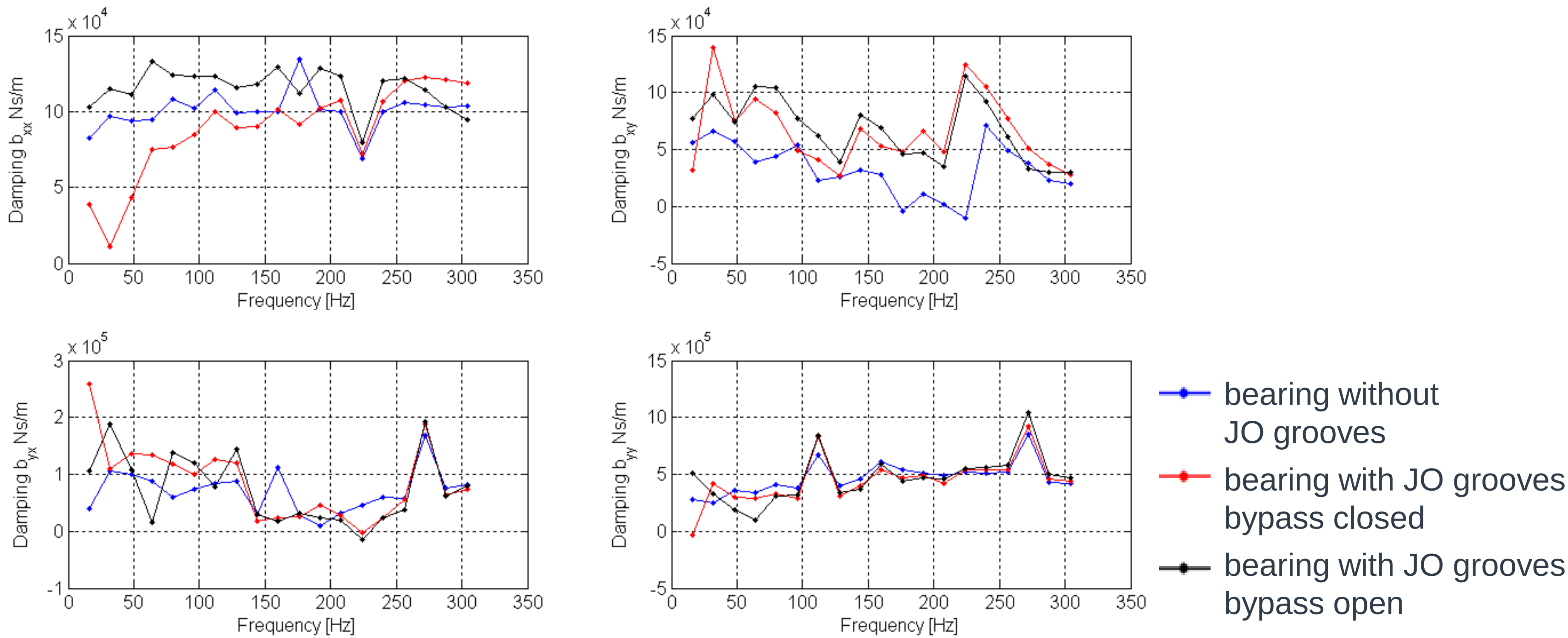


- Opening of bypass yields a change in horizontal stiffness k_{xx}
- No significant effect on vertical stiffness k_{yy}
- No significant difference in cross coupled stiffness k_{xy} and k_{yx}, which can cause rotor instability

→ Change in stiffness does not explain beneficial effect of open bypass

Bearing Test Results

Damping Coefficients: 1,5MPa, 11300RPM (188Hz)



- Opening of bypass yields significant increase in subsynchronous horizontal damping b_{xx}
- Bypass has no significant effect on damping components b_{yy}, b_{xy} and b_{yx}

→ Increased damping verifies the observation of lower SSV of axial compressor on-site

Conclusions

Subsynchronous vibrations on an ASU Main Air Compressor

- During commissioning of an axial compressor subsynchronous vibrations were measured that had not been observed during the mechanical test run
- An extensive root cause analysis showed that subsynchronous vibrations
  - were caused by external excitation most-likely from fluctuating steam flow
  - could be influenced by the JO system of the two-lobe journal bearings
- The practical problem could be solved by installation of a bypass between the two JO feed lines

Bearing test

- The phenomenon was further investigated by conducting a test on scaled test bearing in a test rig at the NRC, Canada
- A simplified JO system was attached to the test rig to measure the effect of the bypass setting on the bearing performance
- The test confirmed that opening of the bypass valve yields
  - a pressure equalization and oil flow in the JO lines
  - a change in eccentricity and
  - a significant increase of the subsynchronous horizontal damping coefficient b_{xx}

→ All MAN ASU trains are running well and stable with acceptable levels of subsynchronous vibrations.

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